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Sterilized Products

INTRODUCTION

The prime incentive for the development of sterilized milk products is that they can be distributed and stored without refrigeration. The use of milk byproducts in the manufacture of sterilized foods has not been one of the more important means of their disposal, but interest in and production of a variety of sterilized, milk-based products is increasing. The lag in preserving milk products by sterilization is due largely to costs involved in their preparation and packaging, and to processing and storage stability problems. However, technological developments in several areas have contributed to continuing progress in the manufacture of these products. These include: automation in plant processing, improvements in processing methods and equipment including continuous flow systems, aseptic packaging, improved packages, and judicious use of stabilizers and flavoring materials. Some developments have resulted in improved quality; others in new products, greater convenience, or in lower costs.

The sterilization of foods by high-temperature short-time methods, followed by aseptic packaging has gained importance in the dairy industry in recent years. This system has broadened the range of products which can be canned successfully. Sterilized milk, milk products, or milk-based products lend themselves to high-temperature short-time, continuous flow sterilization because of their fluid nature. The degree of fluidity can be controlled over a wide range by the control of the composition, degree of concentration, the use of appropriate stabilizers, and other process conditions. The desired consistency depends on the form in which the product will be used.

Successful canning of milk-based products is generally limited to those having a pH near that of normal milk, especially products containing a high percentage of casein. For example, buttermilk is highly unstable toward heat. Success in sterilizing low pH products may be greater by high-temperature short-time methods than by in-can methods for two reasons: (1) physical and chemical changes brought about by HTST

methods are normally less for a given sterilization effectiveness than when the sterilization is accomplished by retort methods, and (2) homogenization, which tends to destabilize proteins, can be accomplished after sterilization in HTST methods. During recent years several investigators have devoted time to the development of high-temperature short-time sterilized whole milk, HTST 3:1 whole milk concentrate and cream which might compete with the fluid, fresh products. Sterilized creams have been the more successful. The HTST sterilized milks have been used widely by the armed forces, but accepted only on a limited scale in the civilian market. This lack of acceptance may be attributed in part to milk flavor changes brought about by heating and to the development of "staleness" during prolonged storage. Packaging expense is also a factor where the product must compete with marginal profit products. However, new technology has stimulated the development of a variety of sterilized products, especially those in which mild changes in flavor are not detrimental. These include flavored drinks, puddings, toppings, sauces, diet drinks, and specialty products for ingredient use.

Those canned sterilized foods which contain milk or its constituents, with the exception of standard evaporated milk, will be considered in this chapter. The manufacture of evaporated milk has been carefully described by Hunziker (1949). Also the discussion of developments concerning HTST sterilized whole milk and 3:1 whole milk concentrate will be limited to processing techniques, types of equipment, and physicochemical aspects which have general application. Milk, cream, and whey will improve the nutritive value, flavor, and physical appearance of many prepared convenience foods; but in those foods which must be heat processed special manufacturing problems arise. These problems will be discussed and possibilities for the development of new products will be indicated. Such a discussion must necessarily involve the behavior of the fat, protein, lactose, and salts of milk, and the use of stabilizing additives. The milk constituents are present in varing proportions in different milk byproducts.

The U.S. Food and Drug Administration has not promulgated definitions and standards of identity for a majority of the products considered in this chapter. Manufacturers of new products and modified dairy products which will be involved in interstate shipment should seek label advice from the U.S. Food and Drug Administration.

STERILIZING AGENTS

Milk sterilization may be briefly defined as the application of techniques which render the product free of microorganisms which are liable to proliferate. The objective is to preserve the product for an extended

storage period during which it remains of good commercial value. Agents advocated for food sterilization have included heat, radiation, chemicals, high frequency electrical current, pressure, and supersonic sound waves. Of the various methods, sterilization by heat is at present the only accepted commercial procedure. Some of the processes do not produce a sterile product; others result in poor flavor quality or in undesirable chemical changes in the finished product.

Sterilization by Heat

Heat is firmly entrenched as the best method for sterilizing foods. Steam and hot water are the media most universally used, although hot air and heating by electricity have had limited commercial application.

Sterilization by heat is satisfactory for a wide range of products because the heating media (steam or hot water) can be readily measured and controlled. It can be adapted to a variety of equipment designs, including processes in which the product is sterilized in the container and processes utilizing continuous flow sterilization. In the latter system steam can be applied for sterilizing a product either with an indirect heat exchanger or by direct injection of steam into the product. In addition to the product, the container must also be sterilized. When sterilization is accomplished after canning, the container is simultaneously sterilized; but, when packaging is done after sterilization, container sterilization is a separate process, and, indeed, the success of the aseptic packaging process depends in considerable degree on the adequacy of this step. Container sterilization in this case may be accomplished by heat (steam), by chemicals, or a combination of these media.

The effectiveness of a thermal process is a function of both the time and temperature of the heat treatment. Objectives of applying and controlling the heat treatment are twofold: (1) destruction of spore resistant organisms, and (2) preservation of the most desirable product characteristics. Much information is available on the heat resistance of bacteria under a wide range of time-temperature combinations in various products. Within the limits of achieving sterility, some choice in the temperatures and times of heating may be made to achieve certain product characteristics. Generally, it is desirable to use only enough heat for sterilization since many of the milk components are adversely affected by excessive heat.

Sterilization by Radiation

The discovery of the nuclear fission process and developments in nuclear energy during and since World War II have made available a range of ionizing radiation sources for research on "cold sterilization" of foods. Extensive research in this area has been sponsored by the Atomic Energy

Commission and by the U.S. Army Quartermaster Research and Engineering Command, Natick, Massachusetts. Thorough discussions of radiation processing of foods are given by Desrosier (1963) and by Heid and Joslyn (1967). Several other reports on the radiation preservation of milk have been published (Wertheim *et al.* 1956; Hoff *et al.* 1958, 1960A; Saravacos *et al.* 1961).

Destruction of bacteria and other biological, chemical, and physical changes brought about by ionizing radiations (beta particles, cathode rays, gamma rays and X-rays) result in insignificant temperature increases; hence, the term "cold sterilization." Even with only small changes in temperature, ionizing radiations result in numerous chemical changes in foods. These changes affect both flavor and physical stability of the product. Wertheim *et al.* (1956) encountered a browning, or Maillard-type of reaction, and other off-flavors after exposing milk to radiation. Hoff *et al.* (1958) observed a radiation-induced gelation in milk concentrates exposed to gamma rays (^{60}Co) and high voltage electrons. Even with radiation dosages of 1.86×10^6 rad, sterilization was not complete. It was necessary to add antibiotics to preserve the milk for storage studies.

Day (1966) classifies off-flavors resulting from gamma irradiation of milk fat as having three components: hydrolytic rancidity, oxidative rancidity, and candlelike. He proposes chemical reaction mechanisms for the formation of several compounds. These include: aldehydes, ketones, free fatty acids, carbon dioxide, and hydrocarbons.

Enzymes are much more resistant to ionizing radiations than microorganisms (Heid and Joslyn 1967). Consequently, other means of inactivating enzymes would be necessary. Heat, no doubt, would be the best method to use in conjunction with radiation sterilization. Schultz and Lee (1966), in a review of the present status of food preservation by irradiation, state that milk, even at levels of irradiation sufficient only for pasteurization purposes, now appears to be out of the question from the standpoint of both acceptability and feasibility. Clearly, more basic and applied research are needed if this method of sterilizing milk or milk-based products is to be used commercially.

Other Sterilizing Agents

Chemicals used for sterilizing milk have included hydrogen peroxide, chlorinated hydrocarbon vapors, and certain antibiotics. The Italian hydrogen peroxide process developed during World War II (Dahlen *et al.* 1945) consisted in treating milk with 2% by weight of a 39% solution of the peroxide and allowing the milk to stand 8 hr. The number of bacteria decreased to a minimum 12 hr after addition of the peroxide and thereafter increased. Attempts to sterilize milk with antibiotics showed that

streptomycin was uniformly ineffective in killing spores, whereas penicillin was effective only against certain spores (Curran and Evans 1946). Nisin was studied by Heinemann *et al.* (1965) as an aid to sterilization of foods. Its addition to several foods, including chocolate milks, evaporated milk, cream, and milk substantially reduced the heat treatment required for commercial sterility. The lower heat treatment resulted in flavor improvement, increased vitamin retention, and improved keeping quality.

A centrifugal method of producing a sterile milk is claimed in which milk at 71°C is passed through a special centrifuge to remove all but a small fraction of *Micrococcus* organisms (Business Developments 1968). These are destroyed by subsequently heating to 71°C for a short time. The primary claim in the report is that the separation of bacteria is made possible by a much reduced viscosity at 71°C.

HEAT PROCESSING METHODS AND EQUIPMENT

Heat treatments of milk and milk products are the most important steps employed in the processing plant. Heating is employed mainly for the purpose of preservation, which includes pasteurization and sterilization. It is also employed in conjunction with such steps as homogenization, evaporation, the mixing of ingredients, and to impart special properties to products, such as an increased viscosity and a greater protein stability.

Presterilization Heat Treatments

Byproducts of milk are usually subjected to at least two heat treatments during the course of manufacture into sterilized products. One of these is that of forewarming, or preheating, which usually precedes concentration under vacuum, homogenization, sterilization, and other phases of manufacture. It is employed mainly to stabilize the protein against possible heat coagulation during subsequent sterilization. This step usually immediately precedes evaporation so that the product can be introduced into the vacuum pan at a temperature above the boiling point within the pan. This facilitates efficient removal of water and a rapid cooling of the product. The second heat treatment is the sterilization process itself. Special methods and pieces of equipment have been developed for preheating and for sterilizing milk and its byproducts.

Methods of Heating.—Preheating may be accomplished either in a heating vat (hot well), or by high-temperature short-time methods. When milk products are heated in a hot well temperatures of 190° to 212°F are normally employed. The holding time will depend on the temperature used, the stability of the milk, and product characteristics such as viscosity, color, and flavor desired in the finished product. A holding time of about 10 min is typical for hot well forewarming. Heating in a hot well is generally accomplished either by injecting steam directly into the milk

product or by means of a steam-heated jacket built around the vessel. Steam injection is a rapid and efficient means of heat transfer, but requires the use of culinary steam. The steam condensate also dilutes the milk.

High-temperature short-time methods of preheating, employing such time-temperature combinations as 255° F for 15 sec, or 300° F for 1 or 2 sec may also be used. Such HTST methods, accomplished under continuous flow conditions, are generally more adaptable to present-day high volume, automated processing than methods using jacketed vats, or hot wells. Either indirect heating, or direct steam injection may be used for these methods. Equipment designs for HTST indirect heating systems include both tubular, and plate-type heat exchangers. "Burn-on," or deposition of milk solids on heating surfaces of indirect systems is a problem which shortens process time before cleaning becomes necessary. Direct steam injection, or combinations of direct and indirect heating may be used to diminish this problem.

It is important for the processor to determine the requirements of his product with respect to preheating conditions and types of equipment needed. The effects vary greatly with product composition, treatment history, and method of heating used. The general effects of preheating, though not thoroughly understood, are empirically arrived at. A discussion of the physical and chemical effects of heating are given in a later section of this chapter.

Sterilizing Processes and Equipment

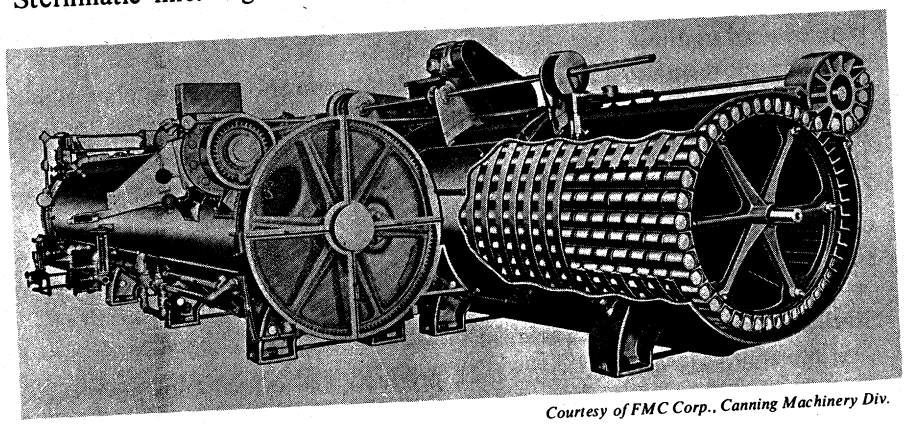
Many methods for sterilizing milk products and other foods have been developed and patented. The advances made in the early developments of sterilization processes have been reviewed by Ball (1938) and by Jackson and Benjamin (1948). Since the latter review, many additional reports on new methods and types of equipment have appeared. The methods used for dairy products can be conveniently divided into two types: (a) retort sterilization in which the product is sealed in the container before it is heated, and (b) sterilization in heat exchangers under continuous flow conditions, followed by aseptic packaging. High-temperature short-time processes have been devised for both retort and continuous flow sterilization methods. The latter method is frequently referred to as the aseptic process, ultrahigh temperature (UHT) process, or as the high-temperature short-time (HTST) process. Since some confusion may be caused by the term HTST, in the following discussion the conditions of sterilizing will be specified when this method (HTST) refers to retort processing.

Retort Process.—The retort, or autoclave, is the basic piece of equipment for the sterilization of many foods. Various designs are available. These include still retorts, agitating "batch" sterilizers, continuous hy-

drostatic systems, and continuous agitating sterilizers. Equipment is available for handling products packaged in both glass bottles and in cans. Descriptions of several types of retort sterilizers are given by Burton *et al.* (1965) and by Heid and Joslyn (1967).

In order to manufacture sterilized products of a high standard of uniformity, it is essential that each container be exposed to the same heat treatment with respect to times and temperatures of heating. It is also desirable that there be rapid heat penetration throughout the can so that the temperature within the container is as uniform as possible. Consequently, mechanical and operational features have been constantly improved so that agitation of the container is rapid and uniform.

The most widely used continuous retort (in-can) sterilizer for milk products is that manufactured by the FMC Corporation, called the Sterilmatic line. Figure 8.1 shows a diagram of one such design. The



Courtesy of FMC Corp., Canning Machinery Div.

FIG. 8.1. CUT-AWAY VIEW OF CONTINUOUS IN-CAN STERILIZER SHOWING SPIRAL REEL DESIGN

equipment comprises sections for preheating, sterilizing, and cooling. The sealed cans enter the unit through a valve and are advanced continuously through each section in a spiral mechanism. The purpose of the preheater is to pass the cans through a temperature gradient so that the pressure difference between the product and heating medium is reduced enough to avoid partial can collapse when entering the high pressure in the sterilizing section. The cans are transferred from the preheater to the sterilizing section, and from the sterilizer to the cooling section by means of specially designed pressure values.

Steam is utilized in the sterilizing section. The temperature in this section can be varied from about 240° to 270° F. The transit time of the cans through the sterilizer can be adjusted to correspond to any selected temperature so that the desired "sterilizing effectiveness" is obtained. In

the cooling section adequate air pressure is applied until the cans are cooled sufficiently to prevent them from buckling as a result of their internal pressure.

The continuous retort is equipped with automatic temperature and pressure controls, and a variable speed drive which permits the processing of a wide range of products, and can be designed to accommodate several different can sizes.

Ultrahigh Temperature or Aseptic Processes.—These processes involve the heating of the product to temperatures ranging from 130° to 150° C for times of a few seconds, then cooling, and packaging the product under aseptic conditions. In order to obtain and control these high temperatures and short "hold" times, it is necessary to heat the product under continuous flow conditions (outside a container). Several different makes of UHT sterilizers are now available. The types of equipment may be divided into two groups, depending on the system of heating: (a) those in which the product is heated by direct contact with steam, and (b) those utilizing indirect heat exchangers. Indirect systems include tubular systems of various designs, plate, and scraped-surface types of heat exchangers. The heating medium for these systems is usually pressurized hot water or steam. Each system may have advantages or disadvantages compared to the others, depending on type of product, flow rate, and other processing steps employed along with sterilization. For example, plate heat exchangers are suitable for low viscosity products, and can be designed for very efficient heating and cooling of the product. Scraped-surface types may be required to handle highly viscous products, semisolid products, or products containing discrete particles.

Direct steam heating may be accomplished either by injecting steam into the product, or by admitting the product into a chamber containing an atmosphere of high pressure steam (infusion heaters). The injectors are smaller and less expensive than the infusers, but require a higher operating temperature. Also the high velocities resulting from injection heating may cause greater physical damage to certain types of products than infusion heating. With any type of direct steam heating, the steam must be of culinary quality, and with some products, it may be necessary to remove the steam which condenses in the product so that the original composition is maintained. This can be done by flash evaporation, which is an advantage in that it provides a means of extremely rapid cooling.

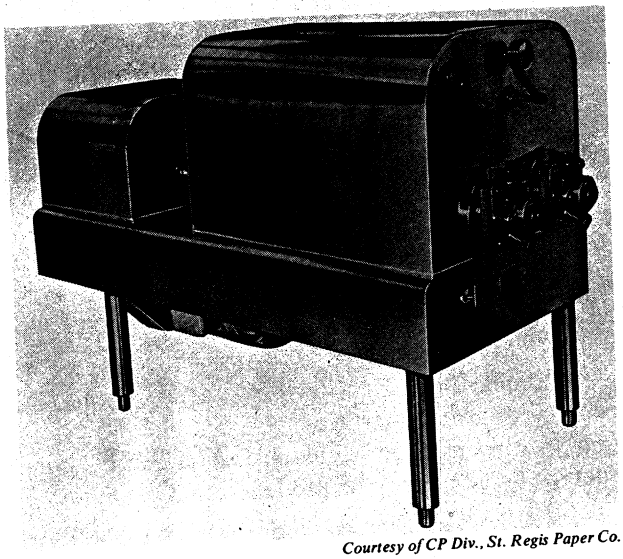
Several recent papers describe UHT processing equipment and current commercial applications. In a series of articles Burton (1965A, B, C, D, E, F, 1966, 1969) describes in considerable detail available equipment for UHT sterilization with particular reference to their use with aseptic filling methods.

The articles are oriented toward European developments, and con-

sider primarily sterile whole milk. Burton also contributes to a thorough discussion of UHT processes and equipment in another publication (Burton *et al.* 1965). Lang and Lang (1966) and Arph (1965) also discuss briefly the developments in this field.

Hall and Trout (1959), Pflug *et al.* (1959), Hedrick (1967), and Seehafer (1968) review and discuss the merits of aseptic processing and canning equipment in the U.S. Many aspects of aseptic processing, including bacteriological, chemical, and physical changes, and equipment designs, efficiences, and arrangements are also discussed in detail in another recent booklet (Cherry-Burrell Corp. 1968).

A photograph of an indirect scraped-surface type of heat exchanger is shown in Fig. 8.2. The unit consists of jacketed cylinders about 6 in. in



Courtesy of CP Div., St. Regis Paper Co.

FIG. 8.2. INDIRECT SWEPT-SURFACE HEAT EXCHANGER FOR HEATING OR COOLING HIGHLY VISCOUS OR SEMISOLID PRODUCTS

diameter and from 4 to 6 ft in length. Heating or cooling medium fills the jacket around the cylinder. In the particular unit shown, product enters the right front cylinder, passes to the left cylinder at the rear and exits at the front of the left cylinder. Motor driven scrapers continuously move the product away from the heat-exchange surface. The cylinders may be arranged in multiple units to provide for both heating and cooling in a unitized system.

In Fig. 8.3 is shown a direct injection heater, followed by a holding tube and a vacuum chamber for flash cooling. Preheated milk is discharged

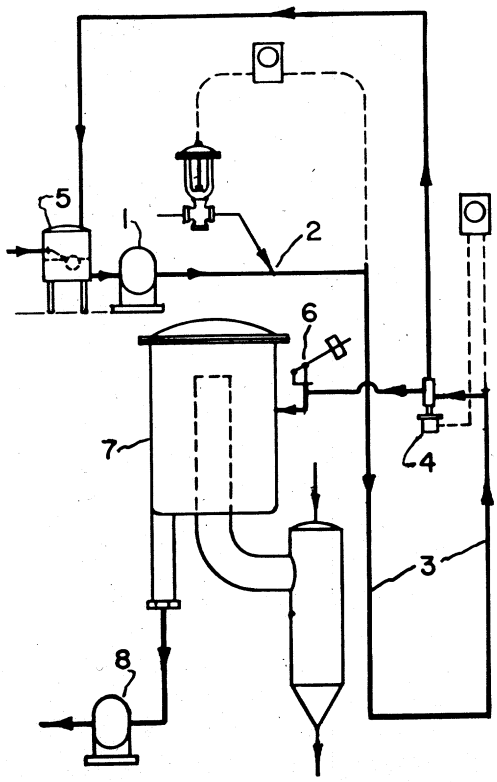


FIG. 8.3. SCHEMATIC OF DIRECT STEAM INJECTION HEATER COUPLED WITH FLASH-COOLING VACUUM CHAMBER

(1) Timing pump, (2) steam injection heater, (3) holding tube, (4) flow diversion valve, (5) surge tank, (6) weight-loaded valve, (7) vapor-liquid separator, and (8) pump.

under positive pressure from the timing pump (1) through the steam injection heater (2), then through the holding tube (3). A flow diversion valve (4) is connected at the outlet of the holder tube which is operated by a recording controller actuated by a thermal bulb. Thus, any milk below the desired temperature is diverted and passes back into the surge tank (5). Milk that has been thus heated at the predetermined temperature is ready to be vacuum cooled. It is still under pressure of the timing pump (1) and passes through a weight-loaded valve (6) which causes a back-pressure on the holding tube but allows the heat-treated milk to enter the vapor-liquid separator (7) which, if the milk flow has been diverted, seals off the vapor-liquid separator. The milk is flash cooled in the vapor-liquid separator to a predetermined and controlled temperature corresponding

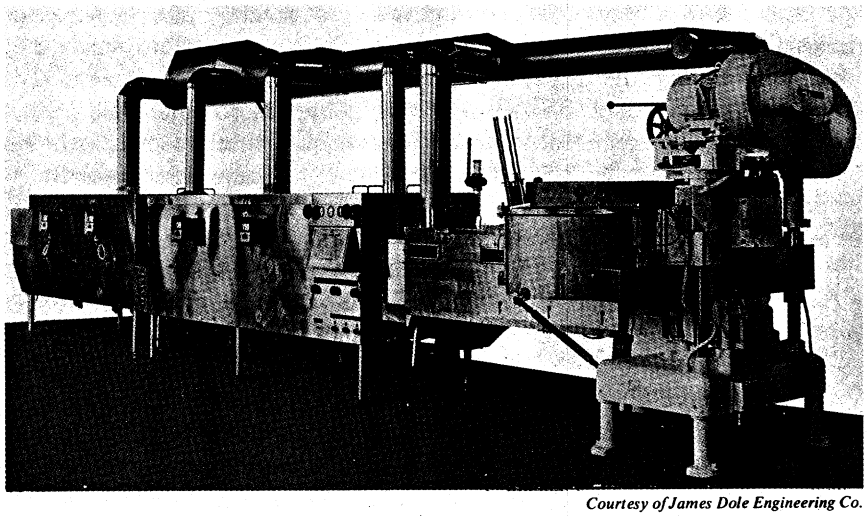
to the vacuum in the vapor-liquid separator. At this stage, the water injected in the form of steam during the steam injection stage is removed. The heat-treated and vacuum-cooled milk is withdrawn from the vacuum chamber by a pump (8), then flows into receiving tanks and is aseptically packaged.

Advantages of the system are rapid heating, a minimum holding time, and rapid cooling. Mechanically, this system is somewhat complex. A pump is required to transfer the product under aseptic conditions to a packaging unit. Also, an aseptic homogenizer may be required. The system can be arranged with or without regenerative features. It is flexible in that a wide range of capacities can be accommodated, and can be used with high and low viscosity products.

Packaging and Containers for UHT Sterilized Milk Products

At present only two container types are used commercially for aseptic packaging of UHT sterilized milk products. These are metal cans used by the Dole aseptic canner and laminated paper Tetra Pak cartons. Research is underway to develop methods for sterilizing glass containers for aseptic filling of liquid milk products. Any type of aseptic filling equipment must sterilize the container, then fill and seal it without atmospheric contamination. Ideally, a container for milk should be inexpensive, lightweight, attractive and convenient for consumer use and have the ability to withstand the handling necessary to package and distribute the product. It must also remain hermetically sealed during storage. The containers currently used have one or more disadvantages with respect to the above features. For example, the metal can is expensive, and the paper carton is relatively fragile and not suitable for large-size containers. Nevertheless, the advantage of improved product quality gained from aseptic processing outweighs these disadvantages with respect to many products.

Metal Cans.—The most widely used aseptic packaging system in the U.S. is the Dole Aseptic Canning System manufactured by the James Dole Engineering Co. A photograph of one design of this type of filler is shown in Fig. 8.4. In this installation the cans are sterilized with superheated steam at atmospheric pressure as they are conveyed through the sterilizer to the filler. The containers are raised to a temperature of about 400° F. The covers, similarly sterilized with superheated steam, are contained in a cover sterilizer which is operated as an accessory to the closing machine. The cold sterile product, which flows continuously from the heat exchanger, is filled into the sterile cans as they are conveyed from the can sterilizer. The cans are sealed by standard types of closing machines under sterile conditions. Models of this type of aseptic canner are made to accommodate cans with capacities from 4.5 to 136 oz. The



Courtesy of James Dole Engineering Co.

FIG. 8.4. DOLE ASEPTIC CANNING SYSTEM

bulk of canning done by this system has been in No. 10 cans (3 qt), which are standard for institutional use, but products packed in smaller containers for home use have been increasing. Johnson (1968) reports the development of a can of 12 in. diam, and having a capacity of 5 gal., or more, which can be aseptically filled and sealed by the Dole system.

Glass Bottles.—Packaging of products aseptically in glass is a difficult task since glass will not normally withstand the thermal shock to which containers are usually exposed in steam sterilization methods. Burton *et al.* (1965) report that a cream product has been aseptically bottled in small glass containers. Cream which stays sweet for months is also reported to be aseptically packed in glass containers in another article (Anon. 1962). Mitten (1968) reports that an aseptic glass bottle filler with a rate of 200 bottles per minute is in the developmental stages in the United Kingdom.

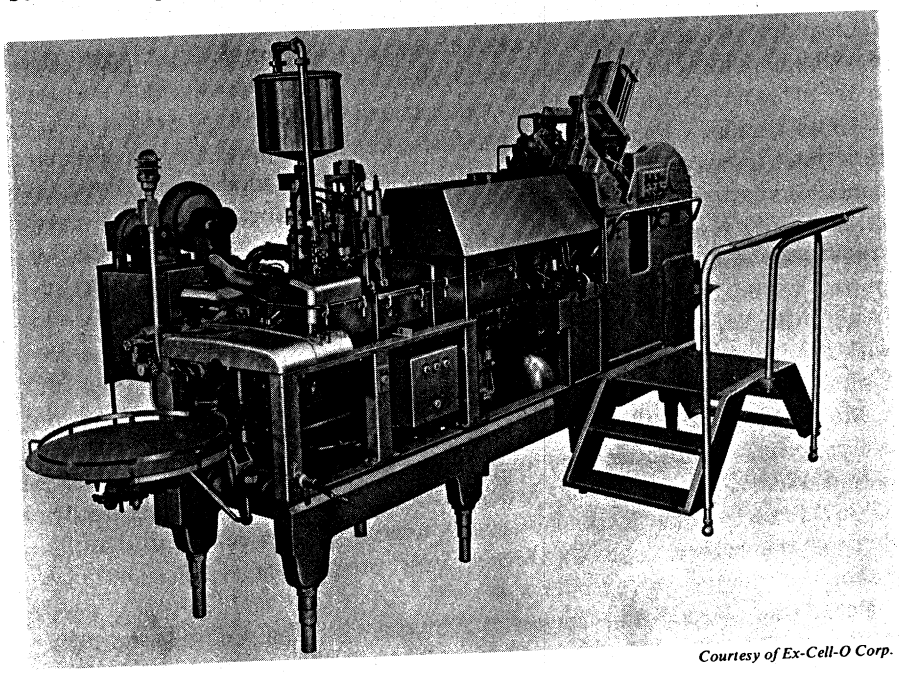
Manufacturers of the Dole aseptic canning system have designed, and are reported to be testing, equipment for aseptically packaging 8-oz jars (Anon. 1968A). The containers are subjected to wet steam at a temperature of 307°F for 1.5 to 2 sec. The short exposure time reportedly avoids thermal shock (breakage) by treating only the surface of the glass with steam.

Paper Containers.—The Tetra-Pak container is being used to aseptically package UHT sterilized milk in Europe, but has only a very limited use in the U.S. For aseptic filling purposes, the Tetra-Pak material, which is reinforced with aluminum foil, is sterilized with dilute hydrogen peroxide.

The excess hydrogen peroxide is removed by squeezing, after which the material is formed into a tube and finally sterilized with hot air inside the tube. This causes the residual hydrogen peroxide to decompose and vaporize. This carton is inexpensive, but is limited to small-sized containers and has an inconvenient shape. The manufacturer of this carton is developing a rectangular shaped carton of one-liter capacity (Tetra-Bric) for use in aseptic filling of milk (Anon. 1968B). Its shape should provide for more convenient storage of the carton than that of the Tetra-Pak.

Recent developments with the Pure-Pak carton, which is widely used in the U.S. for pasteurized milk, are reported which make possible its use for aseptic packaging. The carton is formed from five-ply laminated material which is sterilized with a chemical applied as a fog after bottom sealing. The layers are, from inside out: polyethylene, aluminum foil, polyethylene, paper, and polyethylene. After the cartons are dried with hot air, they are aseptically filled and sealed in a sterile atmosphere. The system handles cartons from ½ pt to quart sizes. A photograph of the packaging machine is shown in Fig. 8.5.

Plastic Containers.—Research and development is being carried out by several companies in the U.S. with blow-molded plastic containers for



Courtesy of Ex-Cell-O Corp.

FIG. 8.5. ASEPTIC PACKAGING SYSTEM FOR FORMING, FILLING, AND SEALING IN LAMINATED CARTONS

aseptic packaging of milk products. Machines designed for molding plastic containers of this type are equipped with heating chambers which melt polyethylene beads, and dies into which the melted plastic is inserted before blowing. The beads are blown to the heating chamber where they are heated to about 400°F and extruded as a long hollow tube. This is automatically cut off at each end as it passes into the die. It is then blown into the desired shape and cooled with a refrigerant as soon as the bottle is blown. The mold is then opened. The temperature needed to melt the plastic is apparently sufficient to sterilize the bottle. Filling and sealing of the bottles under aseptic conditions are problems apparently not yet perfected.

Ice cream is being filled aseptically into flexible plastic bags (Finley *et al.* 1968). The bags are sterilized in a chamber with ethylene oxide gas after which the chamber is purged with sterile air. After filling aseptically a portion of the contents is heat sealed from the rest of the package so that it can be removed for testing without contaminating the remainder of the package.

Pflug *et al.* (1963) reported on experimental studies carried out to evaluate the sterilization of foods in flexible packages. Other workers (Nelson and Steinberg 1956; Keller 1959) had previously reported on the feasibility of retorting foods in plastic bags. Some plastic materials will withstand processing at 250°F.

Time-temperature Sterilization Values

The destruction of all microorganisms likely to proliferate is the prime consideration in selecting the times and temperatures for a sterilization process. Since spores are more heat resistant than vegetative cells the thermal process must inactivate the spores. The lethal effect of heat on microorganisms is a function of the time and temperature of heating, the bacterial (spore) population, types of organisms present, and the composition and pH of the product. In essence, at constant temperature, the inactivation of organisms occurs at an exponential rate (excepting such phenomena as "lag phase"). As the temperature is increased the rate of inactivation increases. For many organisms an increase in temperature of 18°F reduces the inactivation time by tenfold. For example, 5 min at 250°F, and 30 sec at 268°F are equivalent insofar as organism destruction is concerned. The number of degrees Fahrenheit required to decrease the heating time by tenfold for equivalent inactivation is referred to as the z value. This value is determined experimentally for an organism under conditions of interest to the processor. The z value is obtained from a thermal death time curve which is represented by a plot of the logarithm of the holding time versus the temperature of heating.

The sterilizing value (F_o) of a heating process is defined as the time in minutes at 250°F required to inactivate a population of organisms under specified conditions. The F_o and z values are used extensively in evaluating the effectiveness of thermal processes. A thorough discussion of the methods of thermal process computations is found in books by Ball and Olson (1957) and Heid and Joslyn (1967). Mathematical treatment of thermal processes which are specifically applicable to UHT sterilization are given in other papers (Pien 1965; Cherry-Burrell Corp. 1968). The value of z associated with a particular product varies with the type of spoilage organism, but values of 16 to 19 include the range encountered under most processing conditions.

However, a processor should be aware that there are variations from the nature of spoilage organisms typified by species normally encountered. One possible variation is that unusually high heat resistant organisms may occasionally be present. This probability increases as contamination of the raw product becomes more severe. As an example, Speck and Busta (1968) report conditions under which one sporeformer displayed a z value of 35°F. Another possible problem is that some spores may acquire an added heat resistance after being exposed to sublethal temperatures. It is also probable that the real nature of the semilogarithmic representation of spore survival after heating at a constant temperature is not linear with time, but of a sigmoid shape (Pien 1965). This means that the rate of destruction of the last surviving spore is less than at the beginning of the heating process. This complicates predictions of spore populations after a given heat treatment. Even with these possibilities, from a practical standpoint, sufficient safety against spoilage can be provided by using either a little higher temperature or longer holding time than that calculated.

Many factors must be considered in designing a system for sterilization. These include the F value required, and z value associated with the product, heat penetration rates, the heating and cooling rates, maximum temperature the product will withstand from the physical stability and flavor viewpoint, and flexibility with respect to changing process conditions and type of product. Extensive information is available with respect to F_0 and z values for a wide range of test conditions. For an accurate determination of the F_0 value, the lethality effected by the heating and cooling portions of the process must be included in computing the sterilizing value. This is particularly important for indirect UHT processes which have a short holding time relative to the come-up time. In practice the F_0 value of a process should be somewhat greater than the theoretical value as determined by heat resistance data in order to provide for a safety factor.

The maximum temperature a product will withstand without unacceptable physical or flavor changes must be considered in the selection of the time-temperature process conditions for sterilization. This includes the come-up time and cooling rate as well as the time of holding at maximum temperature.

For computing the sterilization values of thermal processes for liquid and semiliquid food products in the temperature range of 260° to 300° F, alignment charts are used which relate the 4 process factors, time and temperature of heating, and the F_0 and z values. Any one of these can be computed readily if the other three are known. Usually z is known from previous tests. The chart can be extended readily to handle values at lower sterilization temperatures such as those employed with retort processes.

Computations of sterilizing values for retort processes are more involved than for UHT systems. A process for retort sterilization must be designed to effect lethality at the slowest heating portion of a container. Heat penetration data are needed to calculate the sterilization value of retort processes. The rate of heating in containers depends on the physical properties of the product such as viscosity and degree of particulate matter, size of the container, heat transfer characteristics of the heating medium and of the container, temperature difference between the heating medium and the product, and on the degree of agitation of the cans. Extensive studies have been carried out on heat penetration in canned foods by Bigelow *et al.* (1920), Ecklund (1949), and by Alstrand and Ecklund (1952). Calculations of thermal processes required for a variety of foods are treated in detail by Olson and Stevens (1939), Stumbo (1948), Hicks (1952), Bail and Olson (1957), and Heid and Joslyn (1967).

Typical thermal processes for sterilizing fluid milk types of products in a container are:

243° F for 15 min
262° F for 2 min

The times given above are holding times and do not include the heating and cooling portions of the processes. Longer holding times may be required for products containing particulate ingredients.

The slope of the thermal death time curve (z value) is the basis for selecting sterilization processes over a range of time-temperature combinations. Equivalent changes in product components (besides microorganisms) such as flavor, color, vitamins, serum protein denaturation, and casein coagulation may also be measured in terms of z values. An example of the difference between the z values of spore destruction and of other quality factors is illustrated in Fig. 8.6. The z value for the spore destruction curves is 18° F, which is typical for many food types as well as types of organisms. Several such curves, $F_0 = 6$ to $F_0 = 40$, are shown for

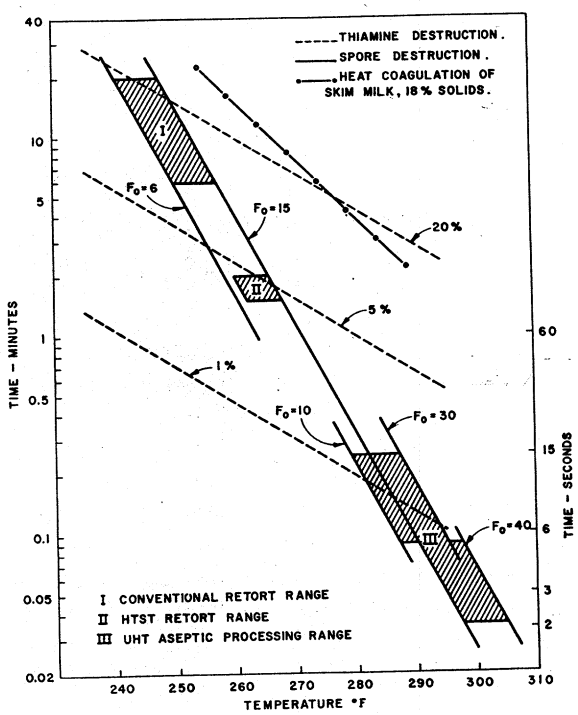


FIG. 8.6. THE TIME-TEMPERATURE STERILIZATION CURVE COMPARED WITH THE HEAT COAGULATION OF SKIM MILK (18 % SOLIDS) AND WITH 1, 5, AND 20% DESTRUCTION OF THIAMINE

reasons which will be explained below. The z value for thiamine destruction is 48° F (Feliciotti and Esselen 1957), and for the heat coagulation of skim milk of 18% solids is approximately 35° F (Holm *et al.* 1923). It will be noted that for a conventional retort process of about 22 min at 240° F (F_0 = 6), 20% of thiamine is destroyed. An equivalent UHT process (spore destruction) of 280° F for 8 sec results in the destruction of less than 1% of thiamine. This phenomenon, illustrated by the differences in the slopes of "equivalent change" curves, is also responsible for improved flavor quality of some heat sensitive food products sterilized by UHT methods compared to conventional retort sterilization. High temperature agitating retorts, such as are used to sterilize products for about 2 min at 262° F, can also be used to improve the color and flavor of sterilized products.

Since all of the F_0 lines for spore destruction in Fig. 8.6 are shown as parallel lines, the z values are equivalent. The 3 cross-hatched areas in Fig. 8.6 indicate time-temperature ranges for 3 different sterilizing systems. The areas are shown to indicate that considerable flexibility in

choice of time-temperature combinations is usually available to a processor for sterilizing. The selection of specific sterilizing conditions will depend on the nature of the product such as heat stability and fluidity, heat transfer characteristics, degree and type of original contamination, and product properties which are desired as a result of the heating process. The time-temperature combination is limited, of course, in the minimum range by the need to achieve sterility. Similarly, upper limits are dictated by the need to avoid undesirable effects of heat on product quality.

It will be observed in Fig. 8.6 that range I is shown between F_0 values of 6 and 15, whereas range III (UHT process) is shown between F_0 values of 10 and 30 in the lower UHT range, and between 15 and 40 at still higher temperatures. This offset is made to show that as the holding times become shorter, somewhat higher than normally predicted temperatures may be needed. This is to provide safety against enzyme reactivation, and against possible survival of organisms which have thermal death time slopes (z-values) greater than those normally encountered.

The phenomenon of enzyme reactivation occurs only in the case of UHT sterilized and pasteurized products, and is most strikingly observed in the case of phosphatase. Wright and Tramer (1953) first found reactivated phosphatase in Uperized milk. The extent to which the phenomenon is a problem is not well-established. It occurs after several days of storage at room temperatures. Very little reactivation takes place under refrigeration. Enzymes which are likely to be of most concern are ones which would result in off-flavors, for examples, lipase and proteases.

Ashton (1965) found wide variations in phosphatase reactivation in sterilized milk but no peroxidase activity under any storage conditions. Edmondson *et al.* (1966) found that phosphatase reactivation was greatest in UHT sterilized whole milks and whole milk concentrates when pre-

TABLE 8.1

THE EFFECT OF PREHEAT TREATMENT AND HOMOGENIZATION ON THE REACTIVATION OF PHOSPHATASE IN STERILIZED 3:1 WHOLE MILK CONCENTRATE

Sample	Preheat Treatment	Sterilization Treatment	Homogenization Pressure	Phosphatase Activity (Phenol Units) Days of Storage 0	14	56
Raw milk	None	None	0	1260	—	—
2	None	300°F—1 sec	0	<4	76	160
3	255°F—15 sec	300°F—1 sec	0	<4	20	40
4	None	300°F—1 sec	4000 psi	<4	<4	25
5	255°F—15 sec	300°F—1 sec	4000 psi	<4	<4	10

heating and homogenization were not employed. In fact reactivation was almost completely suppressed in all samples when they were homogenized at 4000 psi. Table 8.1 shows this effect and also the effect of preheating on phosphatase reactivation in sterilized 3:1 whole milk concentrate. In these studies lipase reactivation was negligible. Wallander and Swanson (1965), however, encountered rancid flavors due to lipase activity in sterilized ice milk mixes. Although it is frequently suggested that proteases may be reactivated on storage, evidence for their presence in sterilized products is lacking.

PHYSICAL AND CHEMICAL PROBLEMS

Important physical and chemical changes associated with heat processing and storage of sterilized milk products are heat coagulation, development of body or viscosity (including gelation), sedimentation, fat separation, color, and flavor. Some changes are desirable, others are objectionable and constitute definite problems which many processing operations are designed to obviate. The extent to which physical and chemical changes constitute problems depends on the type of product and the flexibility of the processing operation. A small degree of coagulation, for example, produces a desirable thickening in such products as evaporated milk and ice cream mix, but is objectionable in most products. Also, the heated flavor resulting from forewarming and sterilizing milk products is quite objectionable when the product is to be consumed as beverage milk, but is largely masked in such flavored drinks as chocolate, strawberry, and vanilla.

Heat Coagulation

The coagulation of milk can be readily brought about by such agents as rennet, acid, and heat. Rennet coagulation, which occurs as a gradual formation of gel structure, is basic to cheese making. Acid coagulation, a sudden precipitation of milk casein, is used in casein manufacture. The heat coagulum of milk usually forms slowly during heat treatment and, if it is allowed to proceed quiescently, a gel structure similar to that caused by rennet is formed. The characteristics of the coagulum which forms, whether by heat or other agents, depends on the conditions that prevail during the coagulation process.

The coagulation of milk by heat is the result of the aggregation of the caseinate particles which form a three-dimensional network from the normal colloidal dispersion of discrete casein micelles. The process of heat coagulation is first observed by an increase in viscosity, then by either a gel structure, a partially coagulated grainy condition, or separation from the whey as a flocculant precipitate.

The resistance of the caseinate particles to aggregation (coagulation) during heat processing is usually referred to as "heat stability." Heat stability may be defined in terms of the time required to induce coagulation at a given temperature. For test purposes coagulation is usually considered to be the point at which granulation begins, and is recognized subjectively under standard conditions.

The caseinate particles in normal milk are composed of calcium, inorganic phosphate, magnesium, and citrate in addition to several casein proteins. (See also Chap. 11.) These particles vary in size, i.e., they are polydisperse. They are relatively large—colloidally dispersed—but remarkably stable to extremes of temperature and concentration. Although unusually stable in the "normal state," they are extremely sensitive to the addition of salts and to changes in pH. Casein is completely insoluble at pH 4.6, whereas the serum proteins are little affected. Conversely, casein is little affected by forewarming temperatures, whereas serum proteins are irreversibly denatured. Factors affecting the heat stability of milk are discussed by several authors (Jenness and Patton 1959; Rose 1963; Tumerman and Webb 1965).

The main factors affecting heat coagulation are: (a) time and temperature of the heat treatment (forewarming), (b) the acidity or pH, (c) concentration of salts and ions, (d) concentration of total solids, (e) homogenization, and (f) the presence of inert and nonionized material.

Time and Temperature of Heat Treatment.—Forewarming is the process of applying heat to milk in order to increase its heat stability after concentration but before sterilization. Numerous reports demonstrate that the time and temperature, and method of forewarming affect the heat stability of evaporated, whole, and skim milk (Webb and Bell 1943; Davies and White 1959; Hartman and Swanson 1962). The mechanism by which forewarming results in greater stability of a subsequently sterilized milk concentrate is not thoroughly understood. Nevertheless, it is widely used as a means of controlling the physical character of such products. Forewarming, although significant in processing, cannot be considered an isolated factor. It results in changes in other factors mentioned above, particularly in pH and in the ionic composition by converting soluble calcium and phosphates to a colloidal form (Kreveld and Minnen 1955; Evenhuis 1957; Rose and Tessier 1959; Kannan and Jenness 1961; Pyne 1962). Forewarming also denatures whey proteins. Denaturing is manifest by such changes as cooked flavor, lowering of curd tension, and a decreased solubility of the whey proteins. Thus they precipitate with casein upon acidification. Heat denaturation of β-lactoglobulin, which constitutes the major portion of the whey proteins, in the presence of casein results in an association between the two proteins (McGugan *et al.* 1954; Traut-

man and Swanson 1959; Sawyer 1969). Attempts to explain the effect of forewarming on heat stability have considered all of the above changes. Although substantial progress has been made in relating the complex changes to heat coagulation problems, a satisfactory theory has yet to be realized. Optimum forewarming specifications are still developed chiefly by trial and error.

Acidity and pH.—Hydrogen ion concentration exerts a marked influence on heat stability, but again its effect cannot be considered an isolated factor. Its relationship, for example, to salt concentration is such that changes in one factor result in changes in the other. The titratable acidity or pH of milk is not generally adequate to determine heat stability, because milks having only slightly different pH values may vary considerably in heat stability. Early work indicated that there is little relationship between the natural acidity of fresh milk and heat stability, but that small changes in pH resulting from bacterial growth or from direct acid additions cause marked decreases in heat stability. Several authors have reported a maximum in curves relating heat stability to pH (Sommer and Hart 1926; Webb 1928; Benton and Albery 1926). The maximum for each milk varied, but most were in the pH range of normal milk (6.6 ± 0.05).

Rose (1961A, B), using refined measurements of pH and heat stability, located the maxima for all samples tested within the pH range 6.5–6.7. The curve passed through the maximum, then declined, often abruptly, to a minimum stability in the pH 6.7–6.9 range. At higher pH levels, heat stability increased to very high values. The pH of maximum stability was found to fall either above or below the pH of the original milk. Thus, some milks were stabilized by small additions of acid, others by small additions of base. Samples stabilized by small additions of acid were also stabilized by small additions of calcium, but this effect was attributed to the acidity developed in the milk by the calcium chloride. Rose (1962) also suggested that the effect of forewarming on heat stability of milks of normal concentration is much less than most authors report. He points out that many previous tests were made without pH adjustment.

The addition of acids directly or of acid foods such as tomato juice will quickly destabilize milk if such addition causes the pH to drop below 6.5. A critical pH value cannot be given but small shifts from the original pH of the milk will often sharply lower heat stability.

High temperature forewarming may cause increases in acidity through cleavage of ester phosphate from casein, or through production of acids, such as lactic and formic, from lactose degradation. These effects, however, are only slight at temperatures below 100° C.

Salts and Ions.—The forewarming of milk (e.g., 90° C for 10 min) results in the precipitation of calcium and magnesium phosphates and

citrates. The addition of sodium salts of phosphate and citrate also decreases the polyvalent cation (calcium and magnesium) concentrations. These facts are the basis of Sommer and Hart's (1919) "salt balance" theory, which conceives of the optimum heat stability as being dependent on a certain ratio of calcium and magnesium ions to those of phosphate and citrate. This concept is the basis for practical procedures for controlling stability of evaporated milk during sterilization by adding disodium phosphate (or sodium citrate). Some milks, but rarely, may require added calcium ion (calcium chloride).

Rose (1963) reviews recent literature concerning the relative concentration of ions in milk and their relation to heat stability. He points out that, although the effect of certain added salts (phosphates and citrates) is sometimes dramatic and useful, there is no definite correlation between individual ionic species and heat stability. He concluded that, to a considerable extent, the effect of these additives is the result of changes which they bring about in the pH of milk. In any case, the concentration of hydrogen ions and inorganic ions in milk, and the effects of forewarming and concentration on these ions, are interrelated factors.

Milks of normal concentration may react differently toward ionic changes than do their concentrated products, e.g., some milks stabilized by polyvalent anions (phosphates) before concentration require the addition of divalent cations (calcium) for stabilization after concentration. After concentration to a solids content greater than 14%, milk can generally be stabilized by the same salts which are used for stabilization at normal concentration. Every milk represents a different colloidal system for which heat stability and amount of stabilizing salt must be determined experimentally. In commercial practice this is done by adding graded levels of a suitable salt solution to test cans of the milk. After sterilizing on a pilot scale, the milks are examined for heat stability and body characteristics. The level of added salt which imparts the most satisfactory stability is noted and used to stabilize the lot to be sterilized.

Concentration of Total Milk Solids.—The heat stability of milk decreases progressively with increasing concentration of milk solids. Figure 8.7 shows this effect, and also the effect of forewarming on stability of skim milks of different concentrations (Webb and Holm 1932). Concentration is a major factor affecting stability to heat, but is controlled readily. Such a reduction in stability with increasing concentration is to be expected because of marked shifts in salt equilibria, an increased concentration of destabilizing ions, and a reduction in pH.

Preliminary heating or forewarming needed to coagulate the proteins of fresh milk of normal solids concentrations varies from about 2 to 5 hr at 240° F. Only a few minutes are required for coagulation of 2:1 con-

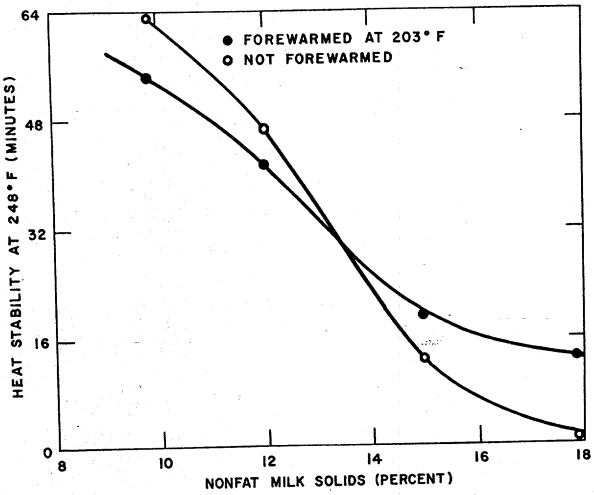


FIG. 8.7. THE EFFECT OF SOLIDS CONCENTRATION AND OF FOREWARMING ON THE HEAT STABILITY OF SKIM MILKS

centrates. Figure 8.7 shows that milks with a solids-not-fat content greater than 14% are stabilized by forewarming before concentration. Milks with less than 13% solids-not-fat were destabilized by the forewarming treatment. Some variations in the relationships are reported by Belec and Jenness (1960). They found that milk from many individual cows was less stable in the concentrated form when previously forewarmed than when no prior treatment was given.

A heat stability test, when used on raw milk, is not available for accurately predicting the stability of the concentrated product. The evaporated milk industry determines heat stability by making pilot tests as outlined in the above section. Forewarming conditions are usually set on the basis of the properties of milk observed during processing on the previous day.

Because of the rapid decrease in heat stability with increasing solids it is difficult to sterilize milk concentrates with solids-not-fat contents much greater than 27% (3:1 concentration). The problems of heat stability of high solids concentrates may be avoided by using high temperature (UHT) sterilization followed by aseptic homogenization and canning. Greater heat stability needed for high solids products may be obtained by high temperature forewarming carried out by direct steam injection or by indirect tubular heaters (Webb *et al.* 1943; Nelson 1949).

Homogenization.—Homogenization is a standard dairy processing operation used principally for stabilizing the fat emulsion against gravity separation. It is particularly important for fat-containing sterilized prod-

ucts which may be stored for months before consumption. Pressures up to 6000 psi may be used in some processes.

In general the heat stability of milk decreases with increasing homogenization pressure. Other conditions of homogenization also have a bearing on stability toward subsequent heating, including temperature of homogenization, fat and solids-not-fat content, and salt equilibria. The effect of homogenization temperature on the heat stability of skim milk, evaporated milk, and creams of different fat contents is shown in Fig. 8.8. The samples of skim milk and evaporated milk were affected very little by the temperature at which they were homogenized. The creams show a maximum heat stability at 176° F and a minimum at about 140° F. If creams are preheated to the optimum homogenization temperature, 176° F, then cooled and homogenized at a lower temperature, such as

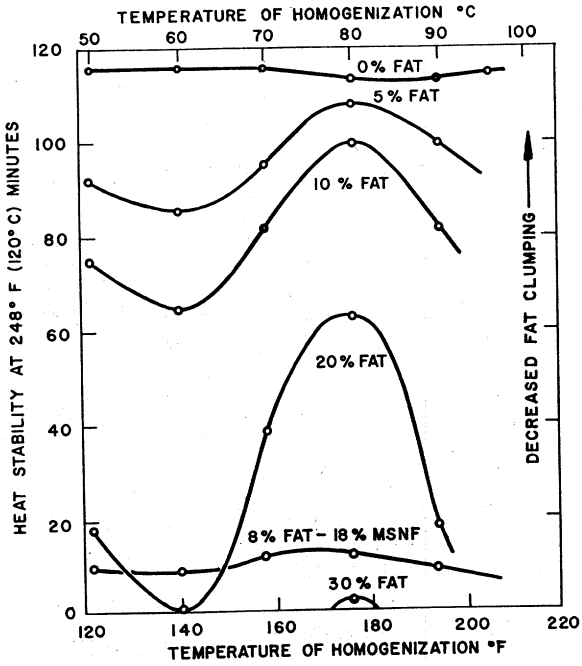


FIG. 8.8. THE EFFECT OF THE TEMPERATURE OF HOMOGENIZATION UPON THE HEAT STABILITY OF SOME MILK PRODUCTS

The evaporated milk sample (8% fat, 18% msnf) was forewarmed to 203° F for 10 min, concentrated to 26% solids and then parts of it were heated to and homogenized at the designated temperatures. All other samples, representing normal skim milk, whole milk, and cream, received no preliminary treatment other than heating before homogenization. These products contained a percentage of msnf normal for products of their fat content.

140° F, their heat stabilities will be almost as low as if they had been heated only to 140° F and immediately homogenized. The actual temperature of homogenization is more important than the prehomogenization heat treatment in the case of high-fat products.

Milk fat in its normal state affects the heat stability of milk very little. Homogenization, however, which reduces the size of the fat globules, results in an increase in the fat surface area where proteins are adsorbed. This is considered a contributing cause of low heat stability of homogenized milk products. The phenomenon of fat clumping, which results from single-stage homogenization of high fat-containing products, and other contributing factors, is also associated with low heat stability. Rehomogenization, or use of a second stage valve used to break up fat clumps and increase heat stability. Homogenization of skim milk and low fat products affects heat stability only slightly. The heat stability of fat-containing products with a normal solids-not-fat content was substantially improved by homogenizing at 176° F compared to 140° F (Fig. 8.8). Maxcy and Sommer (1950) also reported improved heat stability of concentrated milks with increased temperature of homogenization when the homogenization was carried out before preheating and condensing.

Effect of Other Added Materials.—The presence of such materials as fats, sugars, starch, and fruit and vegetable pulps usually promotes protein coagulation in milk products which are heated to high temperatures. The effects of milk fat on stability were discussed in the foregoing section on homogenization. Additives for flavoring, thickening, and stabilizing are used in practically all of the products discussed in this chapter.

The adsorption of proteins by suspended particles appears to be associated with destabilization. Finer dispersions of added materials tend to be more effective destabilizers. Ground casein, tomato pulp, and a fine decolorizing carbon were shown to lower heat stability (Webb and Hufnagel 1950). The same study showed that sugars, including lactose, sucrose, and dextrose, usually lowered heat stability, although dextrose had a stabilizing effect under certain conditions.

Such products as sterilized cream-style soups and sauces should have a smooth consistency free from lumpiness. Since thickening substances, such as starch, usually promote coagulation, processing must be done so that a smooth type of coagulum is produced (Webb and Hufnagel 1946).

Viscosity Changes

Viscosity control during processing and storage is one of the most important considerations in the successful manufacture of milk products. This is particularly true of sterilized products since acceptance is dependent on a uniform consistency for extended storage periods at room

temperature. Control problems range from a marked increase in viscosity during or immediately after processing to a relatively slow gel formation during storage. Age-thinning is also a problem in some products. This problem is sometimes accompanied by the accumulation of a fat layer at the top of the container and sediment at the bottom with a whey-like middle layer.

The viscosity desired in a sterilized product depends not only on the type of product, but also on consumers taste for "richness." For example, the optimum viscosity for a chocolate milk may vary from a highly viscous product to a relatively thin one, depending on the market preference.

The viscosity of sterilized products and changes occurring during processing and storage are affected by many factors including (a) composition and concentration, (b) pH and salt balance, (c) heat treatments, (d) agitation, and (e) addition of stabilizers.

The viscosity encountered in processing of sterilized products is primarily of a structural nature and is usually termed apparent viscosity. This refers to a thickened condition which becomes thinner after agitation. Consequently, the condition for measuring the viscosity of such products must be carefully standardized in order for the values to be meaningful. Instruments for measuring the viscosities of heavy-bodied dairy products include the coaxial cylinder types such as MacMichael and Brookfield viscometers. For relatively thin products the rate of flow through capillary tubes (Ostwald pipette) may be used.

Viscosity is strongly affected by the size and degree of clumping of the fat globules when fat is present. Measurements of fat globule size together with viscosity determinations may give some indication of storage stability. The large viscosity increases which occur during processing and storage are due primarily to changes in the proteins. It is desirable in the processing of many types of sterilized products to obtain a thickening which produces a creamy body. This thickening is a precoagulation change in the milk proteins (particularly casein) which occurs rapidly with increasing concentration, and during a relatively short period of time before the appearance of curd particles. For many products the point of coagulation must not be approached. With others, incipient coagulation is acceptable.

Sterilized byproducts of milk may be divided into four groups with respect to viscosity and body characteristics. These are: (a) the fat-free thin liquids such as skim milk and whey, (b) the evaporated milk group, (c) the cream-soup-type products, and (d) puddings and pie fillings.

The thin fat-free products, represented by plain or evaporated skim milk and whey or skim milk mixtures, have a viscosity range of 1.5 to 30

centipoises. Evaporated skim milk of about 18% solids has found some commercial utilization. Even though the coagulation point of casein is not generally approached in this type of product, caseinate particles tend to settle in the bottom of the can because their specific gravity is greater than that of the serum. Such separation often occurs early during storage. After longer periods of storage the sediment forms a gel-like structure.

The evaporated milk type of products include modified infant milk, sterilized drinks, and canned cream. The usual range of viscosity of these foods is 20 to 80 centipoises. They may contain fats, sugars, stabilizers, and other ingredients to give viscosity and body to the product. High fat in milk and cream is associated with high viscosity values. The increase in the viscosity of cream with increase in butterfat content has been determined by Dahlberg and Hening (1925) and by Babcock (1931). The relationship of viscosity to the stability of the fat emulsion is discussed in a following section.

The casein of milk contributes to viscosity and body development to an increasing extent as the coagulation point of the milk is approached. When products similar to evaporated milk are sterilized in the can, the rate of thickening is greatest during the last few minutes preceding coagulation. Milks of high heat stability do not approach the coagulation point and, consequently do not develop the high viscosity exhibited by less stable milks. The extent to which viscosity develops during sterilization depends on the degree of agitation. Thinner-bodied products will result by increasing the severity of agitation. The critical period during which agitation causes thinning is toward the end of the sterilization process when the coagulum begins to form but is yet scarcely visible. Ultrahigh temperature short-time sterilized products normally show less viscosity than in-can processed products. This difference may be due in part to the high rates of shear (agitation) to which these products are exposed during the heating. Problems of fat separation and sedimentation are also more prevalent as a result of their thin body.

Most products thicken during storage, but evaporated milk made by the usual in-can sterilization method becomes thinner, losing as much as 40% of its original viscosity during the first few days of storage. Excessive thinning contributes to fat separation and even precipitation of casein.

Cream-soup-type products are often semigels and may range in viscosity from 100 to 800 centipoises or more. They possess a much greater apparent, or structural viscosity than evaporated milk types, which often decreases markedly with stirring. These products may contain several ingredients foreign to milk such as vegetable constituents, salt, starch, and meat. These may cause the coagulation of milk proteins in the early stages of sterilization, especially if in-can sterilization is employed. The

precoagulation increase in viscosity ceases long before sterilization is complete. Starch or other binders must therefore be employed to take up the moisture expressed by the coagulating casein so that a smooth coagulum can be obtained.

Canned puddings and pie fillings represent a relatively new group of sterilized products many of which contain milk products as a prime ingredient. Most contain starches, pectins, gums, or other substances to produce a highly viscous, gel-like structure. During processing of these products different conditions are required to form the gel, depending on the composition, type of gel-forming material used, and equipment available. The application of heat with proper agitation aids in gel formation while excesses of either will break the gel. This will cause water to be expressed from the protein-stabilizer structure and eventual separation of constituents during storage. Products of this type are particularly susceptible to shear during the cooling operation, since the colder the material becomes, the firmer the gel.

Sterilization of highly viscous products by retort methods is a difficult task because as the gel forms the heat transfer through the container is reduced. In order to raise the temperature of the center of the container sufficiently to sterilize the contents, overheating occurs near the outside; this results in uneven physical appearance and possibly in poor flavor. This problem is particularly serious when large containers are used. Products in the pudding-type group are well suited to UHT sterilization followed by aseptic packaging, provided the proper design of heat exchanger is employed. Scraped surface designs are normally required especially during the cooling operations. Aseptic processing allows for more accurate control of the continually changing viscosity.

Several methods are available for controlling the viscosity and body of all of the products listed above. Proper homogenization can be used for control to some degree. The homogenizer can be located after the heat treating section in UHT systems which is an important advantage when higher than normal pressures are required. The use of proper preheating, stabilizers, adjustments in pH and salt balance, and variations in degree of agitation, of course, are other means of controlling the viscosity.

Gelation

Gelation is a phenomenon occurring particularly during storage of milk concentrates which have been sterilized by high-temperature short-time methods. It represents stages of increasing viscosity which may range from a slight thickening to a firm gel. These storage changes are to be distinguished from the gel structure desired in the pudding types of products discussed above. The latter is purposely obtained by the use of

special formulations and controlled during processing. Gelation during storage is a defect. Its importance as a problem to be controlled has increased in recent years because the use of UHT (aseptic) processing equipment has increased.

The rate of gel formation increases with increasing product concentration and with increasing temperature of storage. A similar phenomenon occurs in milks sterilized by irradiation without heat (Hoff *et al.* 1960A, B). The mechanism that causes gel formation in irradiated milks is probably related to gelation in HTST sterilized milk since the more severe the heat treatment, the more stable are the milks against thickening. In fact, increased holding times and/or heating temperatures during either the forewarming or sterilization step have been used to retard gelation (Ellertson and Pearce 1958; Stewart *et al.* 1959). This is feasible for products in which some cooked flavor is not objectionable.

Giroux *et al.* (1958) and Calbert and Swanson (1959) report on a procedure for minimizing gelation in UHT sterilized whole milk concentrate by allowing a critical viscosity to develop during a holding period after sterilization. The incipiently coagulated concentrate is then homogenized aseptically to break up the gel. This prevents, or greatly retards, the recurrence of the gel during storage. In effect, this technique is an attempt to correct by mechanical means changes in the molecular structures which are the result of high temperatures. A problem with this procedure is to homogenize the product at the optimum degree of thickening so that the final product remains physically smooth during extended storage periods. Excessive thickening at the time of homogenization will result in "graininess" and possibly sedimentation during storage. If the product is homogenized before the optimum viscosity is developed, gelation will occur.

The most feasible means of controlling gelation during storage is by the addition of polyphosphate compounds. Leviton and Pallansch (1962) and Leviton *et al.* (1963) used a polyphosphate having an average of 4.8 phosphorus atoms per chain for effective stabilization. Commercial hexametaphosphate was also used for this purpose. The storage life of 3:1 whole milk concentrate can be extended by as much as sixfold by adding 0.6 lb of polyphosphate per 100 lb of milk solids to the concentrate before sterilization. Swanson and Seehafer (1963) used pH adjustments with sodium carbonate in combination with added polyphosphate to obtain milk concentrates that are stable for periods up to 1 yr. The disodium phosphate which is commonly used to stabilize evaporated milk against heat coagulation increases gelation (Edmondson 1959; Leviton and Pallansch 1962).

Fat Separation and Sedimentation

Sterilization of milk products by UHT methods normally results in lower viscosity than when sterilization is accomplished by conventional

methods. The lower viscosity is conducive to fat separation during storage. Homogenization is the primary means of controlling this defect and is quite effective for products which are stored for only a few days. Many products such as evaporated milk types, and canned soups and puddings are quite viscous, and when processed with moderate homogenization pressures do not show any significant fat separation for extended storage periods. In such cases the pressure for processing is selected to yield optimum smoothness and body characteristics.

For thin products higher than normal homogenization pressures may be needed to control fat separation. Since the heat stability of milk decreases with increasing pressure, there are limitations to this method. When UHT sterilization is used higher than normal (6000 psi and greater) homogenization pressures can be used, since this step can be performed after sterilization. Even when high pressures are not needed, aseptic homogenization can be used to reduce fat clumping and increase viscosity. Both changes will diminish fat separation.

The viscosity of milk products increases with decreasing temperature; consequently, refrigerated storage is effective for controlling fat separation.

Sedimentation is a separation of solid materials in the bottom of the container. If the settling continues for extended storage periods the material is often very difficult to redisperse. The cause of the problem depends on the type of product, composition, and processing treatment. It is often the result of destabilization of the milk proteins during processing. When the precipitate consists mainly of proteins, it settles as a gel-like layer. It invariably contains other constituents of the product's colloidal system including calcium citrate and calcium phosphate. It may contain a significant amount of milk fat. In some products the salts appear as crystalline deposits. In such cases the defect is observed only after several months of storage. Ingredients other than milk solids, such as fruit or vegetable solids, or cocoa may also be conducive to sedimentation. The added ingredients may settle directly, or cause destabilization of the milk proteins.

Seehafer (1960) studied several factors affecting the storage quality of UHT sterilized whole milk concentrate. Direct steam injection resulted in greater sedimentation than indirect sterilization methods. The use of medium- to high-heat forewarming was found to be the single most important factor in controlling sedimentation problems during storage.

Some treatments utilized to control one problem sometimes accentuate others. For example, high forewarming treatments (used to control heat stability and storage sedimentation) normally accentuate the flavor problem. Consequently, the processor must select carefully; and after considerable experimentation, maintain a balance between the many variables which affect a particular problem.

Like fat separation, sedimentation can be minimized by increasing the viscosity of the product. This has limitations, of course, when the product is to be consumed as a beverage.

Both fat separation and sedimentation can be controlled by the use of stabilizers. These include the alginates and carrageenan. Carrageenan is a polysaccharide extract of certain seaweeds (Irish moss) which is finding wide use in milk and other food products. Wilcox (1958) patented its use for controlling fat separation in HTST sterilized milk concentrates. It is claimed that stability is obtained without substantially increasing the viscosity of the sterilized product.

The standard of identity of evaporated milk has been amended to permit the addition of up to 0.015% by weight of carrageenan. Graham (1963) reports on its use in evaporated milk and related products. He states that in order to maintain the initial viscosity throughout a storage period of several months the amount added must be controlled within a very narrow range. Its level of use also depends on the product and purpose for which it is added. Upham (1963) states that it is used for body development, suspension of insolubles, and prevention of fat separation. Spence (1968) states that it is added to modified infant foods and evaporated skim milk to retard settling, to sterilized milk drinks and diet drinks to suspend such ingredients as cocoa, and to cream soups to improve the mouth-feel. It is also used in combination with starch in canned puddings.

When stabilizers and emulsifiers are added to sterilized milk products, consideration must be given to the processing step during which additions are made, and to their stability toward elevated temperatures. It may be necessary to change the type of stabilizer as some types may break down and lose their effectiveness at high temperatures. It may be desirable to accomplish the desired result with a combination of stabilizers, or by correlating homogenizing pressure and sequence with both stabilizer level and heat treatment.

Color and Flavor

Flavor is of primary importance in the selection of any food we eat. Its importance in milk products is stressed by the magnitude of research being done in numerous laboratories. The recent expansion in flavor research has occurred not only in the chemistry of flavors, but also in the physiology and psychology of sensory perception, and methods of sensory evaluation combined with appropriate statistical analysis of data. Proceedings of several recent symposia on food flavor have been published (Anon. 1966; Schultz *et al.* 1967; Anon. 1969). Included in these proceedings are reviews specifically covering various aspects of flavor chemistry of

milk (Day 1966; Parks 1967; Forss 1969). Jenness and Patton (1959) also discuss several areas of flavors and off-flavors in milk products.

Extensive information in the area of flavor chemistry has recently become available as a result of advances in equipment and techniques for isolating and detecting minute quantities of flavorful compounds. Even though much of the data recently obtained concerns only certain product types, it is probable that the techniques employed, and the classes of compounds thus far isolated and identified will have application to sterilized milk byproducts. Techniques employed to isolate and identify many flavor components include gas chromatography combined with mass spectrometry and infrared spectrometry. These techniques make possible the determination of chemical structure with very small quantities of material which were previously very difficult to study. Even with such refined, sensitive analytical techniques it is difficult to obtain the quantitative information necessary to determine the contribution of many compounds to product flavor. This is because the flavor threshold of some compounds is measured in parts per billion and because the complex mixtures of flavor constituents, available in only very small amounts, must be separated and identified in organoleptically pure form. The chemical information must then be extended to the organoleptic properties of a compound or a mixture of compounds. Teranishi *et al.* (1967) and Teranishi (1969) discuss analytical techniques for flavor research.

Compounds detected by taste and odor may, of course, be either desirable or undesirable. Some may be desirable at a given concentration level or when combined with a mixture of other compounds, but quite undesirable at higher levels, or when they occur in relatively pure forms. Also, a compound may be normal for one product, but distinctly "off-flavor" in another.

This brief discussion of flavor of sterilized milk products will be limited to "off-flavors" developed during processing and storage.

All sterilized milk products exhibit some degree of heated flavor caused either by the production of sulfides or by a caramelization reaction. The specific chemical reactions involved in the development of caramelized flavor are not known but they are accompanied by a brown color (browning) about which considerable information is available. The sulfhydryl flavor is usually described as "cooked" to distinguish it from "caramelized" flavors which develop as a result of more severe heat treatments.

In most products the development of heated flavors and browning are objectionable. Some browning, however, may be desirable in milk products used in making caramel and butterscotch confections. The magnitude of heated flavor and browning problems varies with the type of prod-

uct, methods of processing, and storage temperatures. Cooked flavor is partially removed by evaporation. It also decreases slowly during storage. It is masked to a considerable extent in flavored drinks, soups, and puddings. Caramelized flavor is more persistent; in fact, it may increase in intensity during storage.

Cooked flavor begins to develop in milk when heated to 74° C (165° F) or higher (Gould and Sommer 1939). The flavor is usually attributed to the volatile sulfides, particularly hydrogen sulfide, which are liberated from the sulfhydryl groups of β-lactoglobulin and from proteins of the fat globule membrane (Hutton and Patton 1952). Dimethyl sulfide also apparently contributes to the heated flavor of sterilized milk (Patton 1958). Concentrations as low as 12 parts per billion can be detected organoleptically. Although it is a constituent of fresh milk it has been detected at elevated levels in heated milks (Keenan and Lindsay 1968).

The sulfides are chemically very reactive, having distinct antioxidant properties. This is beneficial when one considers that sterilized products have a low incidence of oxidized flavor.

The contribution of higher molecular weight sulfur containing compounds to flavor has not been thoroughly studied. The use of gas chromatography holds promise for detection and identification of a number of sulfides and mercaptans (Sullivan *et al.* 1959; Feldstein *et al.* 1965).

The formation of volatile sulfides declines as the temperature of heating is increased well above 74° C. At sterilization temperatures caramelized flavor becomes evident. This flavor is probably the result of an interaction of lactose with milk proteins. Patton (1958) states that heat-induced changes in the milk fat may also result in caramelization.

Hodge (1967) discusses the chemistry of specific flavor compounds associated with caramel-like flavor in a number of foods. Although most of the information is concerned with nondairy foods, the flavors are produced from the same types of compounds, namely, reducing sugars reacting with amino acids, peptides, and proteins, under conditions of high heat treatment.

In addition to the heat-induced flavors originating in the skim milk phase, Keeney and Patton (1956) identified a coconut-like flavor (δ-decalactone) in heated milk fat, evaporated milk and other milk products. This flavor is described by Patton (1958) as palatable in certain foods cooked in butter, but as a definite off-flavor in beverage products.

The role of the fat phase in flavors of dairy products is discussed in considerable detail by Day (1966). Literally dozens of organic compounds have been identified as flavor constituents. The compounds which are produced as a result of reactions occurring during processing and storage may be broadly classed as fatty acids, ketones, lactones, aldehydes, alco-

hols, hydrocarbons, and esters. Some of the compounds are beneficial, but many are components of undesirable flavors. Most flavors (desirable and undesirable) cannot be attributed to a specific compound, but to a mixture of compounds. A correlation between chemical identity of flavorful compounds and sensory detection is clearly indicated in some cases, but is a goal yet to be achieved in others. Information is rapidly becoming available in this area.

Stale flavors which develop in sterilized milk products during storage are considered to be the principal off-flavor problem. Flavors of this nature may be derived from both milk proteins and milk fat, although the latter is considered the primary origin of stale flavors. Parks (1967) lists about 40 compounds (ketones, lactones, aldehydes, and acids) which have been reported in stale dry and sterile concentrated milk. Several lactones and methyl ketones are known to contribute to the stale flavor of sterile concentrated milk. One of the latest flavor compounds isolated from sterile concentrated milk is *o*-aminoacetophenone (Parks *et al.* 1964). It is considered an important compound in the stale flavor defect. Arnold *et al.* (1966) identified several long-chain ketones, aldehydes, and lactones in sterile concentrated milk, many of which they considered of significance in the stale flavor defect.

Small amounts of many of the above mentioned compounds, or a mixture of compounds, may impart strong off-flavors in mildly flavored milk products, yet have little significance in highly flavored products. Off-flavors, no doubt, are also contributed by nondairy ingredients when such substances are included in the formulas of milk byproducts.

The prevention of undesirable off-flavors is a problem with which a processor is constantly faced. Slight off-flavors may be eventually accepted by consumers. In any case a processor is confronted with the problem of maintaining a product of uniform flavor quality.

Sterilization by UHT methods causes much less change in flavor and color of products than that brought about by retort processing. Browning and caramelization are insignificant in most freshly processed UHT sterilized products. These improvements in product quality are possible because of the difference between the thermal destruction rates of bacteria and the thermal rates of change in the quality factors. The benefits in flavor obtained by UHT processing are sometimes more significant initially than after a period of storage. Sundararajan *et al.* (1966) showed that an aseptically processed evaporated milk had the best initial flavor score compared to either of 2 in-can processes, but showed very little advantage over a HTST in-can process after 2 months of storage at 50° and 81° F.

The above discussion primarily concerns flavor attributes of a product which are detected by either odor or taste. Flavor sensations are also in-

fluenced by tactual responses due to certain physical properties of a product. These include the sensations of smoothness, astringency, etc., which may be especially important in sterilized byproducts. Stabilizers and emulsifiers are important in this respect for maintaining a uniform quality. It is well known that flavor compounds sometimes occur at levels readily detectable by taste and odor, but defy detection by the most sensitive chemical methods. Likewise, tactual properties are sometimes readily detectable by mouth-feel, but are undetectable by physical means.

Food manufacturers have recently given greater attention to flavor appraisal as a result of consumer's desires for more ready-to-eat foods, more convenience, and also as a result of new flavors made possible by isolation and production of new flavoring compounds. Sterilized milk products can be manufactured with these convenience features and with flavors satisfying to the consumer. Consequently, organoleptic evaluations by either experienced judges or taste panels representing the desired consumer population, are often essential in the successful development and marketing of products. It is the intent here only to indicate the significance of this aspect of product quality. For the interested reader a few of a large number of references on theories and methods of sensory evaluation are suggested. (Dawson *et al.* 1963; Nelson and Trout 1964; Schultz *et al.* 1967; ASTM 1968A,B; Ellis 1969).

Human judgments of flavor are subject to large variations, which are due to differences in individual preferences and to variations in human perception from day to day. This makes necessary the planning of flavor testing so that results can be subjected to statistical analysis. Flavor panels, even when properly conducted are expensive, and can be wasted expense if the information obtained is not properly interpreted. Instrumental methods of flavor analysis can be much less expensive, but are useful only if the results show a significant correlation with organoleptic evaluation. It is the purpose of food flavor scientists to establish correlations between objective chemical and physical tests and human sensory evaluations.

Color formation in sterilized milks during processing and storage is principally of the amino-sugar or Maillard-type of browning. The mechanisms of the reaction and their importance in milk products are reviewed by Patton (1955, 1958). The principal milk components involved are lactose and casein. Specifically, the reaction is a condensation of amino groups ($-NH_2$) of amino acids and proteins and the carbonyl groups ($-C = O$) of sugars (lactose and glucose).

For products forewarmed by batch methods and then sterilized by autoclaving, the heat effects on browning are additive. Patton (1952) showed the effect of preheating at 212° F on the color developed in autoclaved skim milks. The temperature range of 212° to 248° F appears to be critical for development of the brown color.

In addition to heat, browning is affected by total solids concentration, pH, storage time and temperature, oxygen, and certain added compounds. The color intensity developed during heating increases with increasing solids. This effect is primarily one of an increased concentration of lactose and casein. With a given concentration of casein the color intensity developed at autoclaving temperatures is almost proportional to the lactose concentration.

The pH of the product during heating is also a factor of considerable importance in browning. The higher the pH the greater is the tendency to "brown."

Tarassuk (1949) has shown that the color of evaporated milk is less if the head-space oxygen is removed prior to sterilization. This procedure, however, is not considered a satisfactory solution since it is only partially effective. Several chemical agents are known to be effective for inhibiting browning. Patton (1955) has reviewed papers pertaining to this subject and discusses possible mechanisms for the effectiveness of several additives, but concludes that none has received consideration for use in practical dairy processing.

The brown color continues to increase during the first few months of storage. It is greatest in concentrated products stored at elevated temperatures. Means of controlling browning are available for most sterilized milk products. These include the use of high-temperature short-time sterilization, low temperature storage, and marketing as soon as possible after manufacture. The significance of browning in some products may be more of an indicator of poor flavor quality than of objectionable color. It is partly from this viewpoint that the processor should be aware of the factors which cause color formation and means for their control.

TYPES OF STERILIZED PRODUCTS AND METHODS OF MANUFACTURE

A large number of milk-based product types are adaptable to preservation by heat sterilization. The range in choice of formulas depends on (1) use to be made of the finished product, (2) characteristics of the product such as pH and tendency of some constituents to react unfavorably with others, or to undergo change during heat processing, (3) quality of raw materials available, including both milk products and nondairy ingredients, (4) types of processing equipment available, and (5) storage temperatures and time between processing and consumption.

A product selected and processed for use in a ready-to-eat form may have a more limited range in formulations than one to be used in the preparation of other foods, because its flavor and physical character must be of uniform high quality throughout a storage period of several weeks or months. More variation in quality may be permissible if a product is modified or mixed with other foods before serving. A greater freedom in

choice of ingredients and quantities may be exercised when the product is to be refrigerated during storage, or is to be consumed within a short time after processing. Provisions for a speedup in marketing, or refrigerated storage, will greatly diminish many of the troublesome physical stability problems which are otherwise encountered. Costs of ingredients, of course, limit the amounts and types used in formulations.

The following is a list of several types of milk or milk-based products which may be sterilized. Many of these are commercially manufactured, while others are laboratory products.

- Creams of various types
- Milk drinks
  - Flavored drinks
  - Modified infant formulas
  - Diet drinks
  - Eggnog
- Dairy dessert-type products
  - Puddings and pie fillings
  - Milk shakes and milk shake base
  - Custards
  - Ice cream mix
  - Ice milk mix
- Milk-vegetable soups
- Evaporated skim milk
- Filled milk
- Sauces
  - Cheese sauce
  - White sauce
  - Hollandaise sauce
  - Sour cream
- Sterilized cheese spread
- Sterilized butter

A brief discussion of the manufacture and formulation of a few of the listed types will be presented.

Sterilized Creams.—Interest in the production of canned creams began soon after the close of World War I. Early processing was done with in-can sterilization methods. The Grindrod (1939) processes for sterilizing liquid foods have been the basis for the commercial production of HTST sterilized cream (Havighorst 1945). In this process sodium alginate is added to fresh cream to increase the viscosity and keep solids from separating during storage. The selection of good quality cream is considered important. Tests are made to select cream having an acidity below 0.15% for cream of 18% fat and below 0.14% for cream of 30% fat.

After preheating, the cream is sterilized at 260° to 280° F with corresponding holding times necessary to achieve sterility. The sterilized cream is cooled to 150° F and homogenized. Light creams may be homogenized at 2000 psi, first stage, and 500 psi, second stage, while whipping cream of 30% fat may receive little or no homogenization.

The temperature and pressure of homogenization can be varied to control the viscosity and stability of the finished product. This is a particularly useful procedure when homogenization is done aseptically following UHT sterilization. Maximum heat stability, but minimum viscosity,

will result when the cream is homogenized at 176° F. Products of very high viscosity, even semisolid consistency, can be made by homogenizing at temperatures of 110° to 140° F.

Sterilized creams are widely marketed and are packaged in a variety of container types, including coffee cream and half-and-half in ½-oz paper containers. Marketing of sterilized creams is advantageous in that the returns due to spoilage on the grocery shelf can be largely eliminated.

Several recent papers report on the preparation of sterilized creams (Hill and Hay 1963; Swanson 1964; Koops 1967A,B). Research is continuing on processing methods and the use of stabilizers which may improve product quality. Besides sodium alginate several other stabilizers have been used to improve heat stability, diminish phase separation, or to improve whipping properties. These include methyl cellulose, carboxymethylcellulose, monoglyceride, sodium caseinate, carrageenan, guar gum, sodium phosphate, and polyphosphates.

Sterilized Milk Drinks.—Several types of ready-to-drink milk-based products are manufactured. Flavored sterilized milks may be prepared by mixing flavoring material and sugar with whole or skim milk and sterilizing. When whole milk is used, it is normally pasteurized and homogenized before mixing with the other ingredients. Fruit flavored drinks are usually prepared from fruit juice extracts. When chocolate-flavored drinks are prepared special attention must be given to mixing conditions —temperature and agitation—in order to dissolve and suspend the elements in the cocoa or chocolate syrup. Ballester (1965) describes procedures for the preparation of several flavored milk products which may be sterilized by in-bottle procedures. Sterilizing by UHT methods should give equally good or better results.

Several flavors of the so-called 900 cal diet drinks are manufactured. These are usually sterilized by UHT methods. They are high in protein, low in fat, and contain a number of vitamins and minerals and sufficient stabilizer to retard settling of suspended and colloidal particles.

Sterilized infant formulas, also formulated with standardized amounts of protein, fat, carbohydrate, vitamins, and minerals, are manufactured by several companies. Vegetable fats (corn and coconut oils) are usually used in place of milk fat in these products. They are prepared in a concentrated form so that dilution with an equal amount of water will give the desired formula concentration.

Sterilized beverage type products using Cheddar cheese whey as a principal ingredient were reported by Edmondson *et al.* (1966). To prepare the products whey concentrate of about 30% solids is mixed with fresh cream (or other appropriate fat material), stabilizer, sugar, and either cocoa or extracts of strawberry or pineapple flavoring. The ingredients

are combined to give a finished formula of 35% total solids. Carrageenan is used for stabilizing the fat emulsion. After UHT sterilization the products are homogenized and canned aseptically. For serving as a beverage the products are diluted with an equal amount of water. Table 8.2 gives

TABLE 8.2

FORMULAS FOR CHOCOLATE-FLAVORED, WHEY CONCENTRATE-CREAM STERILIZED PRODUCT

Ingredient	1	2
Whey conc. 30% ts	55.0	55.0
Cream, 38% milk fat	20.0	11.4
Chocolate base (double-strength syrup)	10.5	9.5
Sugar	3.0	2.7
Water	11.5	11.4
Carrageenan	0.07	0.063
Total	100 lb	90 lb

formulas for two chocolate flavored products with different fat levels. This type of product can be prepared with a pudding consistency merely by adding starch.

Dairy Dessert-type Products.—A range of viscous products, such as puddings, pie fillings, milk shakes, milk shake base, custards, and ice cream mix may be processed as sterilized products. The use of UHT sterilization gives the manufacturer a greater range in product types than retort processing, although some of these products are sterilized in the can.

McAuliffe (1968) reported on aseptic canning of several flavors of milk puddings and stressed the advantages of UHT sterilization for these products. Reinders (1969) discussed the formulation and processing of several sterilized dairy dessert-type products. A formula for a low viscosity milk shake is given in Table 8.3. The special food starch, high amylopectin grade, is considered essential to obtain the optimum texture and consistency during continuous sterilization. Ordinary corn starch is reported to be unsatisfactory because it tends to gel excessively at temperatures below those used for sterilization. For high viscosity products stabilizers, such as locust bean gum, and gelling agents, such as alginates or carrageenan, may be included in the formula. Emulsifiers may be added if desired. They are added to keep the fat, proteins and particulate materials in a smooth, uniform suspension for extended storage periods.

Suggested formulas for chocolate and vanilla flavored sterilized milk puddings are given in Table 8.4. Low-calorie formulas of each of these

TABLE 8.3

FORMULA FOR A LOW VISCOSITY STERILIZED MILK SHAKE[1]

Ingredient	Amount, Lb
Whole milk	500
Cream (20% fat)	500
Dry skim milk	60
Food starch (high amylopectin cornstarch)	30
Salt	50 gm
Sugars: sucrose	80
dextrose	20
malto-dextrin	30
Coloring and flavoring agents	As desired

[1]Adapted from data of Reinders (1969).

TABLE 8.4

SUGGESTED FORMULAS FOR STERILIZED CHOCOLATE AND VANILLA FLAVORED PUDDINGS[1]

Ingredient	Amount (% by Weight)	
	Chocolate	Vanilla
Fluid whole milk	78.0	84.0
Calcium carrageenan	0.16	0.14
Sugar (sucrose)	15.4	10.40
Starch	2.56	3.00
Salt	0.04	0.04
Fat (including emulsifiers)	1.00	2.08
Disodium phosphate	0.30	0.28
Cocoa	2.56	—
Color and flavor as desired		

[1]Adapted from data of Spence (1968).

may be prepared by omitting the starch and added fat, substituting artificial sweeteners for sugar, and increasing the amount of carrageenan. In the low calorie products the only fat is contained in the whole milk.

Sterilized Sauces.—Sterilized cheese sauce, white sauce, and hollandaise sauce are commercially manufactured. Sour cream is also marketed as a sterilized product.

Weckel and Huang (1969) describe procedures for canning vegetables in cheese sauce. Formulas for several products are shown in Table 8.5. The processing procedure outlined by the authors for canning the vegetables is as follows.

(1) Prepare dry blend of salt, sodium tripolyphosphate, starch, and carrageenan.

(2) Add blend slowly into steam-jacketed kettle containing approximately ½ water of formula.
(3) Agitate for 1 min using moderate speed while heating at 165° F.
(4) Add ground Cheddar cheese, and cheese flavor.
(5) Meter in balance of water.
(6) Blend 2–3 min and heat to 185° F.
(7) Homogenize (2200 psi, 1st stage; 800 psi, 2nd stage).
(8) Hold homogenized sauce at 185° F for 30 min (this hydrates starch and carrageenan).
(9) Fill hot sauce and vegetables into enamel-lined cans at 120° F.
(10) Sterilize at 255° F.

TABLE 8.5

SUGGESTED FORMULAS FOR CHEESE SAUCE FOR VEGETABLE CANNING[1]

	% Ingredients Needed to Make Cheese Sauce						
Vegetable	Water	Salt	Starch	Carrageenan (Viscarin)	Tripolyphosphate	Cheese	Flavor (Enzyme-modified Cheese Solids)
Peas	70.4	1.5	0.7	0.2	0.5	24.7	2.0
Green beans, cut	68.6	1.5	0.6	0.3	0.5	26.4	2.1
Corn, whole kernel	70.4	1.5	0.7	0.2	0.5	24.7	2.0
Carrots, sliced	70.4	1.5	0.7	0.2	0.5	24.7	2.0
Lima beans	74.1	1.2	0.4	0.3	0.5	21.8	1.7
Potatoes, sliced	72.6	1.2	0.5	0.3	0.5	23.1	1.8

[1]From data of Weckel and Huang (1969).

Two-stage homogenization prevents fat-clumping and practically eliminates the problem of fat separation during storage.

The suggested sterilization times at 255° F vary from 11 min for the carrot product to 21 min for the whole kernel corn product. These times are based on heat-transfer measurements.

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